IS THE SUN BECOMING COLDER OR HOTTER?

[By Sir WILLIAM THOMSON, LL. D., F. R. S., F. R. S. E., etc., etc. (now Lord KELVIN).]*

"The question, Is the sun becoming colder or hotter? is an exceedingly complicated one, and in fact, either to put it or answer it, is a paradox, unless we define exactly where the temperature is to be reckoned. If we ask, How does the temperature of equi-dense portions of the sun vary from age to age? the answer certainly is, That the matter of the sun of which the density has any stated value, for example, the ordinary density of our atmosphere, becomes always less and less hot, whatever be its place in the fluid, and whatever be the law of compression of the fluid, whether the simple gaseous law, or anything from that to absolute incompressibility. But the distance inwards from the surface at which a constant density is to be found diminishes with shrinkage, and thus it may be that at constant depths inward from the bounding surface the temperature is becoming higher and higher. This would certainly be the case if the gaseous law of condensation held throughout, but even then the effective radiational temperature, in virtue of which the sun sheds his heat outwards, might be becoming lower, because the temperatures of equi-dense portions are clearly becoming lower under all circumstances.

"Leaving now these complicated and difficult questions to the scientific investigators who are devoting themselves to advancing the science of solar physics, consider the easily understood question, What is the temperature of the centre of the sun at any time, and does it rise or fall as time advances? If we go back a few million years, to a time when we may believe the sun to have been wholly gaseous to the centre, then certainly the central temperature must have been augmenting; again, if, as is possible though not probable at the present time, but probably will be the case at some future time, there be a solid nucleus, then certainly the central temperature would be augmenting, because the conduction of heat outwards through the solid would be too slow to compensate the augmentation of pressure due to augmentation of gravity in the

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shrinking fluid around the solid. But at a certain time in the history of a wholly fluid globe, primitively rare enough throughout to be gaseous, shrinking under the influence of its own gravitation and its radiation of heat outwards into cold surrounding space, when the central parts have become so much condensed as to resist further condensation greatly more than according to the gaseous law of simple proportions, it seems to me certain that the early process of becoming warmer, which have been demonstrated by LANE, and NEWCOMB, and BALL, must cease, and that the central temperature must begin to diminish on account of the cooling by radiation from the surface, and the mixing of the cooled fluid throughout the interior.

"Now we come to the most interesting part of our subject—the early history of the sun. Five or ten million years ago he may have been about double his present diameter and an eighth of his present mean density, or .175 of the density of water; but we cannot, with any probability of argument or speculation, go on continously much beyond that. We cannot, however, help asking the question, What was the condition of the sun's matter before it came together and became hot? It may have been two cool solid masses, which collided with the velocity due to their mutual gravitation; or, but with enormously less of probability, it may have been two masses colliding with velocities considerably greater than the velocities due to mutual gravitation. This last supposition implies that, calling the two bodies A and B for brevity, the motion of the centre of inertia of B relatively to A, must, when the distances between them was great, have been directed with great exactness to pass through the centre of inertia of A; such great exactness that the rotational momentum, or "moment of momentum," after collision was no more than to let the sun have his present slow rotation when shrunk to his present dimensions. This exceedingly exact aiming of the one body at the other, so to speak, is, on the dry theory of probability, exceedingly improbable. On the other hand, there is certainty that the two bodies A and B, at rest in space, if left to themselves undisturbed by other bodies and only influenced by their mutual gravitation, shall collide with direct impact, and therefore with no motion of their centre of inertia, and no rotational momentum of the compound body after the collision. Thus we see that the dry probability of collision between two neighbors of a vast number of mutually attracting bodies widely scattered through space is much greater

if the bodies be all given at rest, than if they be given moving in any random directions and with any velocities considerable in comparson with the velocities which they would acquire in falling from rest into collision. In this connection it is most interesting to know from stellar astronomy, aided so splendidly as it has recently been by the spectroscope, that the relative motions of the visible stars and our sun are generally very small in comparison with the velocity (612 kilometres per second) which a body would acquire in falling into the sun, and are comparable with the moderate little velocity (29.5 kilometres per second) of the earth in her orbit round the sun.

"To fix the ideas, think of two cool solid globes, each of the same mean density as the earth and of half the sun's diameter, given at rest, or nearly at rest, at a distance asunder equal to twice the earth's distance from the sun. They will fall together and collide in exactly half a year. The collision will last for half an hour, in the course of which they will be transformed into a violently agitated incandescent fluid mass flying outward from the line of the motion before the collision, and swelling to a bulk several times greater than the sum of the original bulks of the two globes.* How far the fluid mass will fly out all around from the line of collision it is impossible to say. The motion is too complicated to be fully investigated by any known mathematical method; but with sufficient patience a mathematician might be able to calculate it with some fair approximation to the truth. The distance reached by the extreme circular fringe of the fluid mass would probably be much less than the distance fallen through by each globe before the collision, because the translational motion of the molecules constituting the heat into which the whole energy of the original fall of the globes becomes transformed in the first collision, takes probably about three-fifths of the whole amount of that energy. The time of flying out would probably be less than half a year, when the fluid must begin to fall in again towards the axis. In something less than a year after the first collision the fluid will again be in a state of maximum crowding round the centre, and this time probably even more violently agitated than it was immediately after the first collision; and it will again fly outward, but this time axially towards the places whence the two globes fell. It will again fall inwards, and after a rapidly

* Such incidents seem to happen occasionally in the Universe. [New or Temporary Stars are examples.]

subsiding series of quicker and quicker oscillations it will subside, probably in the course of two or three years, into a globular star of about the same mass, heat and brightness, as our present sun, but differing from him in this, that it will have no rotation.

"We suppose the two globes to have been at rest when they were let fall from the mutual distance equal to the diameter of the earth's orbit. Suppose, now, that instead of having been at rest they had been moving transversely in opposite directions with a relative velocity of two (more exactly 1.89) metres per second. The moment of momentum of these motions round an axis through the centre of gravity of the two globes perpendicular to their lines of motion, is just equal to the moment of momentum of the sun's rotation round his axis. It is an elementary and easily proved law of dynamics that no mutual action between parts of a group of bodies, or of a single body, rigid, flexible, or fluid, can alter the moment of momentum of the whole. The transverse velocity in the case we are now supposing is so small that none of the main features of the collisions and the wild oscillations following it, which we have been considering, or of the magnitude, heat and brightness of the resulting star, will be sensibly altered; but now, instead of being rotationless, it will be revolving round once in twenty-five days and so will be in all respects like to our sun.

"If instead of being at rest initially, or moving with the small transverse velocities we have been considering, each globe had a transverse velocity of three-quarters (or anything more than 0.71) of a kilometre per second, they would just escape collision, and would revolve in ellipses round their common centre of inertia in a period of one year, just grazing each other's surface every time they came to the nearest points of their orbits.

"If the initial transverse velocity of each globe be less than, but not much less than, 0.71 of a kilometre per second, there will be a violent grazing collision, and two bright suns, solid globes bathed in flaming fluid, will come into existence in the course of a few hours, and will commence revolving round their common centre of inertia in long elliptic orbits in a period of a little less than a year. Tidal interaction between them will diminish the eccentricities of their orbits, and if continued long enough will cause the two to revolve in circular orbits round the centre of inertia with a distance between their surfaces equal to 6.44 diameters of each.

"Suppose now, still choosing a particular case to fix the ideas,

that twenty-nine million cold, solid globes, each of about the same mass as the moon, and amounting in all to a total mass equal to the sun's, are scattered as uniformly as possible on a spherical surface of radius equal to one hundred times the radius of the earth's orbit, and that they are left absolutely at rest in that position. They will all commence falling towards the centre of the sphere, and will meet there in two hundred and fifty years, and every one of the twenty-nine million globes will then, in the course of half an hour, be melted, and raised to a temperature of a few hundred thousand or million degrees centigrade. The fluid mass thus formed will, by this prodigious heat, be exploded outwards in vapor or gas all round. Its boundary will reach to a distance considerably less than one hundred times the radius of the earth's orbit on first flying out to its extreme limit. A diminishing series of out-and-in oscillations will follow, and the incandescent globe thus contracting and expanding alternately, in the course it may be of three or four hundred years, will settle to a radius of forty times* the radius of the earth's orbit. The average density of the gaseous nebula thus formed would be (215×40), or one six hundred and thirty-six thousand millionth of the sun's mean density; or one four hundred and fifty-four thousand millionth of the density of water; or one five hundred and seventy millionth of that of common air at an ordinary temperature of $10°$ C. The density in its central regions, sensibly uniform through several million kilometres, is one twenty thousand millionth of that of water; or one twenty-five millionth of that of air. This exceedingly small density is nearly six times the density of the oxygen and nitrogen left in some of the receivers exhausted by BOTTOMLEY in his experimental measurements of the amount of heat emitted by pure radiation from highly heated bodies. If the substance were oxygen, or nitrogen, or other gas or mixture of gases simple or compound, of specific density equal to the specific density of our air, the central temperature would be $51,200°$ C, and the average translational velocity of the molecules 6.7 kilometres per second, being $\sqrt{\frac{3}{7}}$ of 10.2, the velocity acquired by a heavy body falling unresisted from the outer boundary (of forty times the radius of the earth's orbit) to the centre of the nebulous mass.

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* The radius of a steady globular gaseous nebula of any homogeneous gas is forty per cent. of the radius of the spheric surface from which its ingredients must fall to their actual positions in the nebula to have the same kinetic energy as the nebula has.

"The gaseous nebula thus constituted would in the course of a few million years, by constantly radiating out heat, shrink to the size of our present sun, when it would have exactly the same heating and lighting efficiency, but no motion of rotation.

"The moment of momentum of the whole solar system is about eighteen times that of the sun's rotation; seventeen-eighteenths being *Jupiter's* and one-eighteenths the sun's, the other bodies being not worth taking into account in the reckoning of moment of momentum.

"Now instead of being absolutely at rest in the beginning, let the twenty-nine million moons be given each with some small motion, making up in all an amount of moment of momentum about a certain axis, equal to the moment of momentum of the solar system which we have just been considering; or considerably greater than this, to allow for effect of resisting medium. They will fall together for two hundred and fifty years, and though not meeting precisely in the centre as in the first supposed case of no primitive motion, they will, two hundred and fifty years from the beginning, be so crowded together that there will be myriads of collisions, and almost every one of the twenty-nine million globes will be melted and driven into vapor by the heat of these collisions. The vapor or gas thus generated will fly outwards, and after several hundreds or thousands of years of outward and inward oscillatory motion, may settle into an oblate rotating nebula extending its equatorial radius far beyond the orbit of *Neptune*, and with moment of momentum equal to or exceeding the moment of momentum of the solar system. This is just the beginning postulated by LAPLACE for his nebular theory of the evolution of the solar system; which, founded on the natural history of the stellar universe, as observed by the elder HERSCHEL, and completed in details by the profound dynamical judgment and imaginative genius of LAPLACE, seems converted by thermodynamics into a necessary truth, if we make no other uncertain assumption than that the materials at present constituting the dead matter of the solar system have existed under the laws of dead matter for a hundred million years. Thus there may be in reality nothing more of mystery or of difficulty in the automatic progress of the solar system from cold matter diffused through space, to its present manifest order and beauty, lighted and warmed by its brilliant sun, than there is in the wind-

ing up of a clock and letting it go till it stops.* I need scarcely say that the beginning and maintenance of life on the earth is absolutely and infinitely beyond the range of all sound speculation in dynamical science. The only contribution of dynamics to theoretical biology is absolute negation of automatic commencement or automatic maintenance of life.

"I shall only say in conclusion:—Assuming the sun's mass to be composed of materials which were far asunder before it was hot, the immediate antecedent to its incandescence must have been either two bodies with details differing only in proportions and densities from the cases we have been now considering as examples; or it must have been some number more than two—some finite number—at the most the number of atoms in the sun's present mass, a finite number (which may probably enough be something between 4×10^{57} and 140×10^{57}) as easily understood and imagined as numbers 4 or 140. The immediate antecedent to incandescence may have been the whole constituents in the extreme condition of subdivision—that is to say, in the condition of separate atoms; or it may have been any smaller number of groups of atoms making minute crystals or groups of crystals—snowflakes of matter, as it were; or it may have been lumps of matter like macadamising stone; or like this stone (Fig. 50 omitted), which you might mistake for a macadamizing stone, but which was actually travelling through space till it fell on the earth at Possil, in the neighborhood of Glasgow, on April 15th, 1804; or like that (Fig. 51 omitted), which was found in the Desert of Atacama, in South America, and is believed to have fallen there from the sky—a fragment made up of iron and stone, which looks as if it had solidified from a mixture of gravel and melted iron in a place where there was very little of heaviness; or this splendidly crystallised piece of iron (Fig. 52 omitted), a slab cut out of the celebrated aërolite which fell at Lenarto, in Hungary; or this wonderfully shaped specimen (Figs. 53 and 54 omitted), a model of the Middlesburgh meteorite (kindly given me by Professor A. S. HERSCHEL), having corrugations showing how its melted matter has been scoured off from the front part of its surface, in its final rush through the earth's atmosphere when it was seen to fall on March 14th, 1881, at 3.35 P. M.

* Even in this, and all the properties of matter which it involves, there is enough, and more than enough, of mystery to our limited understanding. A watch-spring is much farther beyond our understanding than is a gaseous nebula.

"For the theory of the sun it is indifferent which of these varieties of configurations of matter may have been the immediate antecedent of his incadescence, but I can never think of these material antecedents without remembering a question put to me thirty years ago by the late Bishop EWING, Bishop of Argyll and the Isles; 'Do you imagine that piece of matter to have been as it is from the beginning; to have been created as it is; or to have been as it is through all time till it fell on the earth?' I had told him that I believed the sun to be built up of meteoric stones, but he would not be satisfied till he knew or could imagine what kind of stone. I could not but agree with him in feeling it impossible to imagine that any one of such meteorites as those now before you has been as it is through all time, or that the materials of the sun were like this for all time before they came together and became hot. Surely this stone has an eventful history, but I shall not tax your patience by trying just now to trace conjecturally. I shall only say that we cannot but agree with the common opinion which regards meteorites as fragments broken from larger masses, and we cannot be satisfied without trying to imagine what were the antecedents of those masses."

THE LEANDER McCORMICK OBSERVATORY.*

By H. A. SAYRE.

The LEANDER McCORMICK Observatory is situated on the summit of Mt. Jefferson, at an altitude of about 850 feet above the level of the sea. At the base of the mountain, a mile away, lies the University of Virginia. On the site of the present observatory there once stood a small one, erected in the early days of the university, but afterwards abandoned. The instruments were preserved and are now in the physical laboratory. The present observatory and instruments are the gift of Mr. LEANDER J. McCORMICK, a citizen of Chicago, but a native of Virginia. Through the active efforts of Col. C. S. VENABLE, Professor of Mathematics in the university, the endowment, sufficient to place the observatory on a sound basis, was secured. In 1885 the

* The woodcut which accompanies this paper we owe to the kindness of Dr. W. T. HARRIS, U. S. Commissioner of Education, Washington, D. C.